

Review of the paper “Development of the CMA-GFS-AERO 4D-Var assimilation system v1.0 - Part I: System description.”

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Summary & General Comments

The article presents an overview of the development of a strongly coupled 4D-Var assimilation system where an aerosol atmospheric component, the total mass concentration of black carbon (BC), is added to the 4D-Var control vector. The article contains a detailed explanation of how the necessary linear models have been developed, by extracting and re-coding the BC-related aerosols physical modelling codes and by formulating a specific B-matrix model (and control-vector conversion) for the BC mass concentration. Rather technical validation results are displayed showing the correctness of the TL and AD models, along with preliminary experimental results. The article finishes with an outlook mostly referring to a Part II where the authors intend to discuss comprehensive experimental results on the impact of assimilating BC in a strongly coupled formulation, on the other atmospheric fields (wind, temperature, pressure, humidity).

This article Part I is overall clearly structured, with each section well introduced. As stated by the authors, the aim of the paper is to present the methodology without entering into a complete, comprehensive evaluation of experimental results in full, long-period 4D-Var assimilation experiments. Taking into account that strongly coupled atmosphere-aerosol-chemistry assimilation systems have been very little presented so far in open literature (to the reviewer’s knowledge), the authors’ choice to propose such an introductory Part I can be supported. Nevertheless, the paper focuses too strongly on technical sanity checks (such as the results of tests of TL and AD models which are standard and well-known tests when developing variational codes) which for themselves bring no innovative information. Conversely, the paper lacks explanations on specific scientific challenges that would strengthen the scientific interest of the paper:

1. Compared to the BC physics available in the original CUACE codes, how much has the BC physics for the CMA-GFS-AERO codes been adapted in terms of the representation of the physical processes, such as transport, chemical transformation and the interaction with radiative processes ? Taking this comment one step further, has there been any kind of simplification made when developing the BC physics modules for the linear models, any step of regularization of a non-linear formulation, or any omission of specific complex processes whose linearization was felt too difficult (at least for this v1.0 of the system) ? More explicit explanations should be provided, likely in Sections 3.1 and 3.2.
2. More explanation of why the strongly coupled case provides significantly different results on the analysis fields of the “traditional” atmospheric fields, compared with no BC assimilation or with the weakly coupled case, is missing in Section 4.4. Two striking results are displayed but eventually with very little physical interpretation while both seem to be systematic results:

- a. Adding BC in the modelling and assimilation system rather than omitting this component induces a positive analysis increment on temperature. So question here: should one understand that adding BC in the forecast trajectory *anyway* will slightly increase temperature via the radiative effect of absorption? Is this effect then very systematic ? Is it local or even global ?
- b. Why precisely is strongly coupled assimilation of BC causing an overall decrease of the amplitude of the analysis increments by an order of magnitude ? What are the damping retro-actions ?

The article is fairly clearly written though some specific checking of English phrase construction could be worthwhile. In the specific comments below, a few particularly unclear phrasings are stressed, which deserve further attention and rewrite by the authors. In the bibliographical section, 5 references relate to documents in Chinese. It is unclear to the reviewer what GMD's policy about references in languages other than English is. It might be appropriate that the authors confirm that they can commit to make available translated texts, should they be asked by future readers.

In conclusion, my recommendation is to accept the paper, as a Part I component to be complemented by a Part II, after revision. The goal of the revision, following the comments above, should be to strengthen the scientific explanations of the implementation of BC in the 4D-Var framework as well as to strengthen the physical interpretation of the experimental results displayed in Section 4. A further recommendation could be to extend the paper's title from "System description" to "System description and preliminary experimental results".

Specific Comments & Typos

Section 1.

line 69: what does "PM" stand for ?

Section 2. None.

Section 3.

line 169: "The transport processes for ψ_{bc} are the same as those for the variables associated with the different water species ..."

Re-phrase "water-matter" everywhere in the paper (not sure this is a good English wording, though it is understandable)

lines 175-179 (end of section 3.1):

1. the whole text should be re-written, splitting it into two separate sentences.
2. An additional explanation of how the absence of BC above model level 65 is dealt with in the models should be added. What happens regarding vertical transport for instance ? What's the impact in the adjoint code ?

lines 231-234: "Firstly ..." and later "Secondly ..." => reformulated these two sentences such that there is a verb. Perhaps, try with "Firstly, the distribution weights ... are calculated.". The same construction would apply to the next sentence.

lines 274-277: reformulate that sentence (much too long). Make two separate ones.

line 282: I don't think that a sentence should start abruptly by "And ...". Simply remove this word with no loss of clarity of the text ?

lines 286-288:

1. The vertical correlation model of the background error is expressed as ...
2. Some additional explanation of how this formula has been obtained is required (by analogy to the water species case ? by specific experimental trials ? from external works and then add a reference ?)

Section 4.

lines 315-316: link the two sentences together and remove the start with "And ..." (just use "... and ...")

line 322: again, what does "PM" stand for ?

lines 364-365: replace "filed" by "field". Note that the same typo appears several times later in the text, so the simplest is to make a systematic search and replace

lines 390-391: The sentence "This phenomenon indicates that ..." definitely requires a complete reformulation. It is currently simply not understandable ! What do you want to explain ?

line 395: the caption of figure 4 mentions "simple physics" => what does "simple physics" refer to ? Do the authors refer to specific simplified physics involved in the 4D-Var models (TLM, ADM) ? If this is the case, then more explanations should be provided earlier in the text, for instance in section 3.2 (and also check my general comment above)

line 406: Remind explicitly that the time step is 300s as it's of interest here for the reader to promptly be able to convert time steps into a forecast time length

line 460 and Figure 6. Is the propagation of the BC increment by the wind the generally dominant effect ? Is this what the authors quite generally have been observing in their results ? Or conversely does this statement only apply to the very simplified context of the single-point observation experiments ? (this is what I would derive from the results later in section 4.4 when the effect of full observations strongly-coupled assimilation is shown). Nevertheless, an additional sentence here could be clarifying, in order to avoid misinterpretation with other results shown later on.

line 470. "Figure 7 depicts ... at the initial time of the assimilation window ..."

lines 516-519: should be totally re-written as they are not clear at present. A proposal : "These results suggest that the assimilation of meteorological observations has a small impact on the BC analysis increments. Furthermore, weakly and strongly coupled assimilation seem to lead to similar BC analysis increments."

line 533: "there are certain degrees of analysis increments ..." => this wording is very obscure, please reformulate.

lines 552-558: only to mention that this is the part of section 4.4 that explicitly describes what seem to be interesting physics-related results of assimilating BC, already in these preliminary experiments. This is the part where more physical interpretation of these results is expected, on the feedback mechanisms in strongly-coupled assimilation and about the warm bias on the temperature analysis increment. (Refer to my general comments)

Section 4.5.

Only to mention that I am supportive of this section explaining the computational figures of the enhanced 4D-Var system.

Section 5.

line 614: "surface BC observations"

line 615: "through batch tests"

Acknowledgments.

line 633: "The development of the CMA-GFS-AERO 4D-Var system is a systematic project"
=> what do you mean by "systematic project" ?